SEA-LAUNCH FOR SMALL SATELLITES
AN AMERICAN/RUSSIAN JOINT VENTURE

by

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Abstract

This paper describes practical means of bypassing the two major impediments to the commercial exploitation of space. These two impediments, or constraints, are the affordability, reliability, and availability of launch vehicles on the one hand, and the affordability, availability, and flexibility of launch facilities on the other hand. As to the former, US launch vehicles are noted for their technological complexity, their high cost, and their susceptibility to single point failures. As to the latter, our land launch facilities are costly, inadequate and congested. Schedule delays on one launch cause delays for all succeeding launches from a given launch pad.

The conversion of suitable military rockets (and specifically surplus SLBMs) into satellite launch vehicles will use already paid-for assets and will minimize costs for new construction as well as rocket fuels and oxidizers. Using floating sea-launch techniques already developed, the costs of launch pads, gantries, blockhouses, high capacity water cooling systems, etc., are largely eliminated.

In order to bring the cost per pound in orbit down dramatically, a US/Russian joint venture, Sea Launch Services, has been initiated to convert Russian SLBMs into mobile floating boosters launchable from international waters.

Introduction

In the last half of the 1990's, there will be a dramatic increase in the number of small and medium satellites being placed in Low Earth Orbit. Major contributors will be the Big- and Little- LEO commercial communications satellite developers now vying for the opportunity to develop satellite based cellular phone services for vast areas not now covered by terrestrial cellular providers. Also, satellites will be orbited for various types of observation (landsat, oceanography, weather, ozone sensors, etc.) It appears obvious that lower launch costs would also encourage an increase in the popularity of university and amateur scientific satellites. Capitalizing on the obvious (as well as the not-so-obvious) advantages of the floating sea-launch, we can provide added flexibility with lower cost than by merely continuing along the more traditional path of launching from fixed land-based facilities.

Background

There is an extensive history of launching rockets from the oceans, conducted by the following countries: Germany, the U.S., the (former) USSR, the U.K. and France. Most significant of these have been submarine based ballistic missiles (SLBM's).

Sea-launches of rocket vehicles have been carried out from a variety of platforms from WWII to the present. During WWII, the Germans launched experimental deck-mounted shore bombardment rockets from a submerged submarine off the coast of Peenemunde. This system never became operational.

In the era of the Cold War, the United States, the Soviet Union, the United Kingdom, and France developed submarine carried ballistic missiles with nuclear warheads. These nations have invested heavily in the development and deployment of these strategic strike weapons. In addition, these countries (and many others) have invested heavily in the development of ship-launched anti-air, anti-ship and land attack cruise missiles using rocket boosters or sustainer motors.

In the mid-fifties, Admiral Arleigh Burke, then Chief of Naval Operations initiated the Polaris ballistic missile program. He directed his strategic planning staff to develop a sea-based strategic retaliatory system, using nuclear powered submarines to launch nuclear warhead missiles while submerged. The resulting technique, although a vertical launch, was not floating since the missiles' specific gravity was close to two. The missiles were expelled from the submarines submerged tubes by gas pressure, and their main stages ignited as they broached the surface.

The Soviet SLBM program which followed Polaris by several years was different in two respects. First, the Russians used liquid propellant rockets with a lower specific gravity than the US SLBMs; and, secondly, the rockets were ignited while the nozzles were still in the water. There were indications that several earlier versions of Russian SLBMs were fired from a floating position, after having been released from a submerged submarine. In June 1973, Admiral Thomas H. Moorer, Chairman of the Joint Chiefs of Staff, spoke with General Secretary Leonid Brezhnev at a luncheon in the Nixon White House on Soviet SLBM deployments and the SALT definition of "SLBM launchers". Brezhnev turned to Admiral Moorer, and said, "You are interested in where we launch, I can tell you that we have an infinite number of launch pads!" From an operational standpoint, the similarities between the US and USSR systems were far greater than any technical differences in the missiles fuel types or expulsion techniques. The important thing to recognize is that for both the US and the USSR systems, the capability of successfully operating a highly complex, technically advanced rockets system with demanding guidance and control specs, in a marine environment, was repeatedly demonstrated.

In both the US and the USSR, early tests and experiments in the naval laboratories and launches from coastal waters provided a wealth of engineering data and experience relating to the sea launch in general and the floating launch in particular. Modern technology in the fields of materials, guidance and control, telemetry, and rocket propulsion, render the floating launch approach even more attractive now than it appeared to naval experts in the early 1960s.

Sea-launched rocket launchers for the purposes of scientific or space research, by contrast to sea-launched SLBM missilery, have been quite limited in number. The most notable instances occurred during the International Geophysical Year (IGY). The ARGUS test series conducted during August and September of 1958 yielded data on high altitude nuclear fission effects, and used vertical probe rockets launched from the USS Norton Sound (AVM-1). Similarly, NIKE-ASP sounding rockets were launched from the deck of the USS Point Defiance (LSD-31) to obtain X-ray and ultraviolet data during a solar eclipse.[1] The Soviet Union modified a 3600 ton vessel, the Shokalsky, for scientific research in the fields of meteorology and oceanography. Their probe rockets were deck launched[2], as were the Americans'.

The US Navy's HYDRA Project pioneered the bare (unencapsulated) floating launch. Intended uses were for scientific probes, ballistic missiles, and space boosters. The HYDRA Program was conducted at the U.S. Naval Missile Center at Point Mugu, California, from 1960-1975. Both solid and liquid propellant rockets were used in HYDRA tests. One rather spectacular test was performed in 1960 using a telephone pole 105 feet long, boosted by a surplus Air Force GENIE motor. The telephone pole, highly instrumented (for acceleration and hydrostatic pressure) rose vertically from the Pacific Ocean off the southern California coast.

Most of the experimental HYDRA rockets were merely modified versions of land launched rockets (being suitably waterproofed). They were usually identified with their proper name, prefixed by the HYDRA descriptor. This naming process resulted in such rockets as HYDRA-ARCAS, HYDRA-IRIS, HYDRA-SANDHAWK, etc. The HYDRA-IRIS probe rocket was considered operational from 1963-1970 and was fired successfully eight times (no failures) from widely dispersed locations in the Pacific, Atlantic and Antarctic Oceans The two stage HYDRA-IRIS was capable of lifting a 45 kg scientific payload to 370 km. Basically, the vehicle was a standard IRIS probe rocket manufactured by Atlantic Research Corporation, boosted by three solid propellant Sparrow motors.

Although the HYDRA Program proved quite successful in developing a series of operational floating launch scientific research probe rockets, the succeeding phases for floating launch which had been planned (ballistic weapons and space boosters) were never developed. The US Navy considered HYDRA-type missiles unnecessary in view of the successful development and deployment of the POLARIS missile and its successors (POSEIDON and TRIDENT). As for space boosters, the NASA and USAF jointly held a monopoly on space launches, and strongly opposed development of a family of floating launch satellite boosters, by the Navy.

Although many rockets have been launched from the decks of ships, and thus qualify as "sea-launched", a true sea-launch for larger rockets such as satellite launchers, will be limited to the vertical-floating (or "spar-buoy") launch. Variations of the floating launch have been proposed and/or developed, by Germany, the United States, and Russia countries, over several decades. In the waning days of WWII, the Germans began the development of a capsule launched V-2 ballistic missile. They planned on towing the waterproofed capsule with the missile inside behind a U-Boat, which would surface at night off the US coast. The cylindrical container containing the V-2 Missile was designed to be ballasted to the vertical, and had an upper hatch that opened to allow for firing of the missile. The intended target, was to be New York City, and more specifically the center of Manhattan Island.[3] Fortunately for the American people, this German version of a submarine launched ballistic missile was not implemented before the armistice was signed.

In 1984, there was a totally commercial attempt to develop a floating sea-launched satellite booster based on hybrid rocket technology. This effort by Starstruck, Inc. culminated in the successful test launch of a limited thrust Dolphin test vehicle. A 21,500 pound single stage floating launch test rocket named Dolphin was successfully launched from a floating position off San Clemente Island, California, in August 1984. The launch support ship was a 165 foot oil field supply boat. The rocket was carried on the after deck and launched from a set of roller ramps welded into a "V", sliding the rocket into the water in the manner of launching a ship. Unfortunately, in spite of the successful Dolphin launch, the company ran short of venture capital and went out of business. Remnants of the company were reorganized and re-formed as the American Rocket Company (ARC). Although ARC appears to have abandoned plans to develop complete satellite launcher systems (whether floating or land-based), it is continuing the development of hybrid propulsion stages. These will presumably be sold as components to the major launch providers.

A recent US Navy effort to develop a floating launch capability was the US Navy's Sea-Launch and Recovery (SEALAR) program- initiated by the Naval Research Laboratory. The overall goal was to develop a simple pressure fed liquid satellite booster with recoverable (and reusable) stages.

The planned rocket was to use a kerosene/lox propulsion system; stages were to be recovered through use of aerodynamic decelerators followed by water impact. Following a few air drops of a simulator model from a helicopter with mixed results, the program lost US government funding in

1992. Although a number of studies were completed, this program has resulted in no launches to date, mainly due to the lack of funding. Subsequent to the funding cut-off, the Naval Research Laboratory announced that it has has signed a Cooperative Research and Development Agreement (CRADA) with the Sealar Corporation, a newly formed private corporation headquartered in Washington, D.C.

Advantages of the Floating Launch

Extensive studies and operational tests conducted by the US Navy during the 1960's and early 1970's pointed up many advantages that can be expected by exploiting the water as a launch pad.[4] First and foremost is the high degree of flexibility and mobility that can be provided using this technique. Being able to select launch sites away from populated areas, and with no launch azimuth restrictions is a luxury not available to any land-launch complex in existence. Equatorial sea launches, without costly doglegs to change the orbital plane ensure maximum efficiencies for GEO satellite launches. The next most important advantage is that of safety. Both "launch-pad safety" and "range safety" are ensured: the first because there is no "launch-pad" to damage or destroy, only water surrounds the rocket during firing; the second, range safety, is ensured by selecting trajectories which overfly a clear stretch of unpopulated ocean following liftoff. The safety advantages will ensure a great reduction in third party liability insurance costs. Another advantage of water launching is that erection (changing the rockets position from horizontal to vertical) can be easily accomplished by one man (actuating a ballast valve, for example). This permits rocket buildup, payload integration to be performed aboard ship in the more accessible horizontal position. In the HYDRA tests, experiments covered many different ways of inserting rockets into the water. Quite a few handling methods were found to be suitable, depending of course, on the size and construction of the rocket itself. Some examples are: (1) launching down an inclined ramp, as a ship is launched from its building ways, (2) lifting into the water horizontally with or without a strongback support, (3) lifting the rocket off the deck by the nose and lowering into the water vertically, (4) resting the rocket in the cradle of a seaplane beaching dolly, (5) flooding a drydocked, horizontal booster, and then towing it out to deeper water, where erection is performed.

Another advantage of the floating launch is that one is not limited in the number of rockets which can use the "pad" at the same time. In a large vehicle land-launch (Ariane, Delta, etc.) the rocket generally ties up the pad for at least a month, and usually the pad requires some maintenance or repair after each firing. Yet another floating-launch advantage is that the floating launch pad (water) easily adjusts to changes in rocket geometry (lengthening, adding stages, adding strap-ons, etc.) with little or no effort on the part of the launch provider.

In the HYDRA Program, the time between water insertion and launch was generally quite short-less than half an hour. Erection in the water, even for the largest rockets, will take less than a minute. The support ship pulls off to a safe distance, generally 1-2 km, crosswind, and the rocket is fired by radio command.

The mobility inherent with sea launch permits the launch provider to make effective use of climatology, geography, and other factors that can ensure that near ideal launch conditions prevail before committing to the launch. For rockets as large as satellite boosters, sea states of two or less are desired.

Most significantly, perhaps, is the fact that one does not tie up a launch pad for weeks or months should a problem on one particular launch vehicle or payload occur. In fact, the floating launch uses (as its advocates frequently point out), a "no-cost, self-healing, non-saturable" launch pad!

Use of Surface Ships in Sea Launch

The capability of ships in providing economical transportation for large, heavy cargo and large numbers of people is well known. Perhaps less appreciated is the degree of self-sufficiency and operational flexibility afforded by ships in general. From the uncomplicated coastal steamers to the complex aircraft carrier, a ship is truly a marvel of efficiency and self reliance in the performance of its designed mission. There is little or no wasted space, yet space can be provided in abundance for vital functions. All the habitability requirements for crew and passengers can be met with the desired degree of comfort. If machine shops are required, they are included in the design. If cargo space is needed it is provided. The overall size and hull design are determined by the speed, range and endurance specified by the user. Assuming that a reasonable number of launches per year can be scheduled, the use of such a support ship appears justified. In all of the tests conducted by the Navy from 1960-1970, a number of ships were used without modification, and rockets weighing up to ten tons were transported and launched without difficulty.

Launch Agency for Sea Launch

To date, virtually all sea-launches have remained the province of a government agency. In the United States, this has been the U.S. Navy (some in cooperation with NASA). A similar situation has existed in the USSR (now Russia). The only totally private, non-government sea launch which has been carried out, to the authors' knowledge, is the launch of Starstruck's Dolphin rocket.

The situation with respect to land-launched boosters parallels that of sea-launched boosters. It is largely government dominated in the U.S., but is beginning to open up to commercial launching vehicles and launch teams. Still, extensive use is made of government facilities, particularly for range support, launch pads, etc. The Ariane booster has become commercialized, but there are still strong overtones of control by ESA, a multinational agency, the French government, and Arianespace, (largely owned by the French government).

The only air-launched satellite booster, the Pegasus, recently completed its first commercial launch of two payloads (Brazilsat and an Orbcom communications test satellite). Even this commercial air-launch relied on a NASA B-52, and extensive range support from the NASA Cape Canaveral complex.

Commercial Rocket Launching Defined

It is unfortunate that the launching of satellites has remained so long under strict control of government. Although the design and production of Satellite booster hardware is done by private industry for the most part, management and operational phases have remained virtually a government monopoly. Typical boosters are designed and built to government specifications (MILSPEC or NASA) after being procured under government contract. They are transported to a government range (either at Vandenberg or Cape Canaveral). Finally, they are launched from government property at a government owned launch pad, under government regulations. During launch, a destruct button is usually held by a government range safety officer, while the booster is tracked by government radars, telemetry, and other range sensors. This degree of government control leads to excessive amounts of "red tape" plus bureaucratic impediments and delays almost beyond comprehension. "Commercial Satellite Launching" for purposes of this paper may be defined as follows:

> "..the launching of satellites by a private launch services corporation, using privately procured satellite launch vehicles and support equipment, manned by employees of the corporation or their sub-contractors, with all planning, management and operational control the responsibility of the launch services corporation. Launch operations would be carried out in compliance with government regulations, the law of the sea, and other international norms. In particular, the corporation will provide its own third-party liability insurance and provide adequately for personnel and property safety due to the hazardous nature of certain rocket propellants."

The principal reason for developing sea-based commercial rocket launching services is to extend more completely the advantages of our free-enterprise economic system into the field of satellite launching. Increased efficiencies and cost reductions in boosting satellites into orbit can be brought about through competitive free enterprise, just as these same advantages have been realized in fields such as automobile manufacture or airline operations. Space programs become much simpler, involving contracts between a launch service client (such as a corporation operating commercial communications satellites) and the launch service provider (the corporation providing the boosters and sea launch services).

In the field of satellite launches, a multitude of factors conspire making it difficult or impossible to "find the optimum", or even to determine just which method is efficient from those that are inefficient. Due to government subsidies, excessive layers of management, and overlapping areas of responsibility, costs are bound to multiply. In the authors' opinion, many programs are presently threatened with failure through poorly coordinated, geeographically dispersed effort and multiple responsibility management. Establishing a going commercial rate of X dollars per pound inserted into a nominal orbit by commercial launch service providers in a competitive environment would quickly eliminate the more inefficient operators-considering all factors such as operational concept employed, effective use of technology, and efficient utilization of technical personnel.

Legality of Sea-Launching Satellite Boosters

The proposed use of the high seas or international waters for the purposes of rocket launching raises the question of legality, within the body of international law. The principle that the high seas are open and free to the use of all nations was not fully recognized until the first quarter of the nineteenth century. Now, general practice recognizes this "freedom of the seas" subject only to certain regulations adopted by international conventions for the protection of navigation (e.g., maritime "rules of the road") and fishing, and the suppression of piracy and the slave trade. Order is maintained on the high sea as between individuals by subjecting the internal discipline of each vessel to the law of the state whose flag it flies, irrespective of the nationalities of the parties involved in the case. Each state admits merchant vessels to its registry under conditions of its own determination; and once a vessel flies the flag of a particular state, no other state may question its right to sail the high seas or interfere with its movements in international waters.[5] Rocket launchings which have taken place on the high seas have invariably been carried out without opposition. Typical examples are the numerous tests of submarine launched ballistic missiles (SLBM's). Likewise, both land and sea based rockets impacting the oceans in planned, remote locations (with advance notifications to mariners), have occasioned no objections. Examples are the Apollo reentries, and SLBM test impacts at Kwajalein or Kamchatka. Of prime importance is the fact that there is no depletion of natural resources, nor damage to property, nor loss of life, from such activity.

Another aspect of launching converted SLBMs is involved with implementation of the START Treaty. The 30th agreed to amendment to the treaty addresses the question of launching from international waters, using converted missile propulsion units with warheads removed.

Aside from the question of legality, it is evident that there would be some measure of government control and regulation of a sea-launch service. The transportation of solid or liquid rocket propellants by ship or barge would be subject to safety regulations enforcable by the Coast Guard. Frequency allocations for telemetry and radar transmitters would be subject to control by the Federal Communications Commission (or its foreign counterpart if the vessel were flagged in a country other than the US). Most probably, advance announcement of launches by the launch service provider would be broadcast in the form of Notices to Mariners, to prevent inadvertent steaming into the immediate launch area around the launch time. Even considering these forms of government control, it is evident that the sea-launch operator retains almost complete freedom of initiative- certainly more than can be claimed for any land-based operation.

Formation of Russian/US Joint Venture

Early this year, retired Admiral Thomas H. Moorer, a former Chairman of the Joint Chiefs of Staff, proposed the use of the floating (or HYDRA) launch for commercially launching satellites into orbit.[6] Retired Russian Admiral Fyodor I. Novoselov, former Deputy Fleet Commander for Shipbuilding and Armaments, and now President of the Russian Corporation RAMCON, invited Admiral Moorer and his associates to visit Russia to discuss the creation of a sea-based commercial launch venture. (RAMCON is a Russian acronym for "Association for the Conversion of Submarine Launched Ballistic Missiles"). Admiral Moorer and several of his associates accepted the Russians' offer and discussions were subsequently held in April 1993, in both Moscow and Miass. At the conclusion of the joint meetings in Miass, Admiral Moorer and Admiral Novoselov signed a Protocol of Intent to establish a joint venture to be known as Sea Launch Services. This corporation has been granted exclusive rights to the inventory of former Soviet SLBMs for conversion to satellite launch vehicles. The Makeyev Design Bureau would direct the modification of the missiles. The Makeyev Design Bureau would also provide satellite launching services using these modified Russian SLBMs. The American party would actively promote the commercial and scientific capabilities of the joint venture, locate payloads for launch into orbit, and provide necessary ship/barge support.

The Makeyev Design Bureau (KBM)

The Makeyev Design Bureau (Russian acronym KBM) is located at Miass, in the foothills of the southern Urals, near Chelyabinsk. It is under the direction of I. I. Velichko, who succeeded its founder and only previous director, the highly respected Academician V. P. Makeyev (1924-1985). This Bureau was the technical center which developed Soviet SLBMs. Since 1991, KBM has been actively working on conversion projects for the large family of SLBMs which the Bureau designed (See Fig. 1). The family includes the liquid-propelled Zyb, Vysota, Volna, and Shtil classes (SSN-6, SSN-8, SSN-18, and SSN-23 NATO designators, respectively), as well as the solid propellant Rif (SSN-20). This latter rocket is carried aboard the Typhoon, the world's largest submarine.

To date, there have been three suborbital launches with 17 minutes of zero "G" to conduct biological experiments, using the Zyb rocket. The larger Shtil and Rif rockets can provide an orbital capability for several hundred kilograms to LEO.

Development/Operational Schedule

Sea Launch Services expects to conduct a demonstration launch in the summer of 1994, using a Shtil-1N launch vehicle. (See Fig. 2). The launch will be conducted in the Barents Sea area (in the vicinity of Archangel or Murmansk), and will orbit a small research or communications satelllite payload.

To simplify procedures, the logistic plans for transport and delivery of the launch vehicles will generally parallel those used in the past for transporting missiles to Severodvinsk, the northern seaport where the Russian missile submarines were based. Severodvinsk is near Archangel on the White Sea.

As a follow-on, operational booster, Makeyev Design Bureau will develop the Surf ("Priboi") launch vehicle, by joining the first (solid) stage of the Rif (SSN-20) to the entire (liquid) SHTIL-3N (SSN-23), with warheads replaced by a satellite fairing and payload adapter. This vehicle will be launched about a year following the demonstration launch.
An absolutely watertight, hermetically sealed nose cone fairing, to replace the missile shroud, will ensure a dry environment for satellite payloads.

A cross-section of the Surf booster is shown in Fig. 3. A table showing orbiting capabilities to polar and equatorial orbits in metric units is shown in Figure 4. Two payload shroud configuration options are shown in Figure 5.

Integration of the satellite and rocket may be accomplished either ashore, or on board the support ship or barge. In both cases, the rocket will be assembled in a horizontal attitude, greatly reducing access problems. Everything needed to integrate the payloads, and to check out the launch vehicle, such as workshops, power suppplies, cleanrooms, etc., will be provided aboard the support vessel.

The construction of each of these Surf commercial launch vehicle will remove two strategic nuclear weapons from the Russian Navy stockpile, providing a modern, graphic example of the term "beating swords into plowshares"!

Conclusions

The relatively new field of commercial satellite launch services can now benefit from application of known sea-launch technology using the vertical-floating (HYDRA) launch method. Sea-going launch support ships will operate in international (or national) waters, from mobile launch sites selected for unrestricted azimuths and clear downrange trajectories. Congestion at launch pads (i.e. water site) is eliminated, with the only time delays being due to buildup/assembly/integration time. Increased safety, flexibility, reduced administrative "red-tape" and regulation all lead to lower launch costs. Commercial satellite launches performed by private corporations are found to be technically feasible, economically attractive, and legal from the standpoint of international law. The growing requirements for launch services to low-earth orbit (LEO) and medium earth orbit (MEO) include large constellations of MSS communications satellites, as well as increased numbers of weather, landsat, and scientific research satellites. The Russian/US joint venture, Sea Launch Services, Inc., will serve this customer base, more flexibly, at lower cost, and with more rapid response, than can be achieved with fixed, saturable launch pads and land launched boosters.

Finally, there are those who would try to keep the Russian rockets from being able to compete in the marketplace. We should remember that competition and free markets are symbols of America. We not only help the Russians to pay their bills and stabilize their country by showing them how the free enterprise system works, but we also help those Americans who are looking for an economical way to get their satellites in orbit. Sea-launch offers a practical means for breaking the present land-launch logjam.

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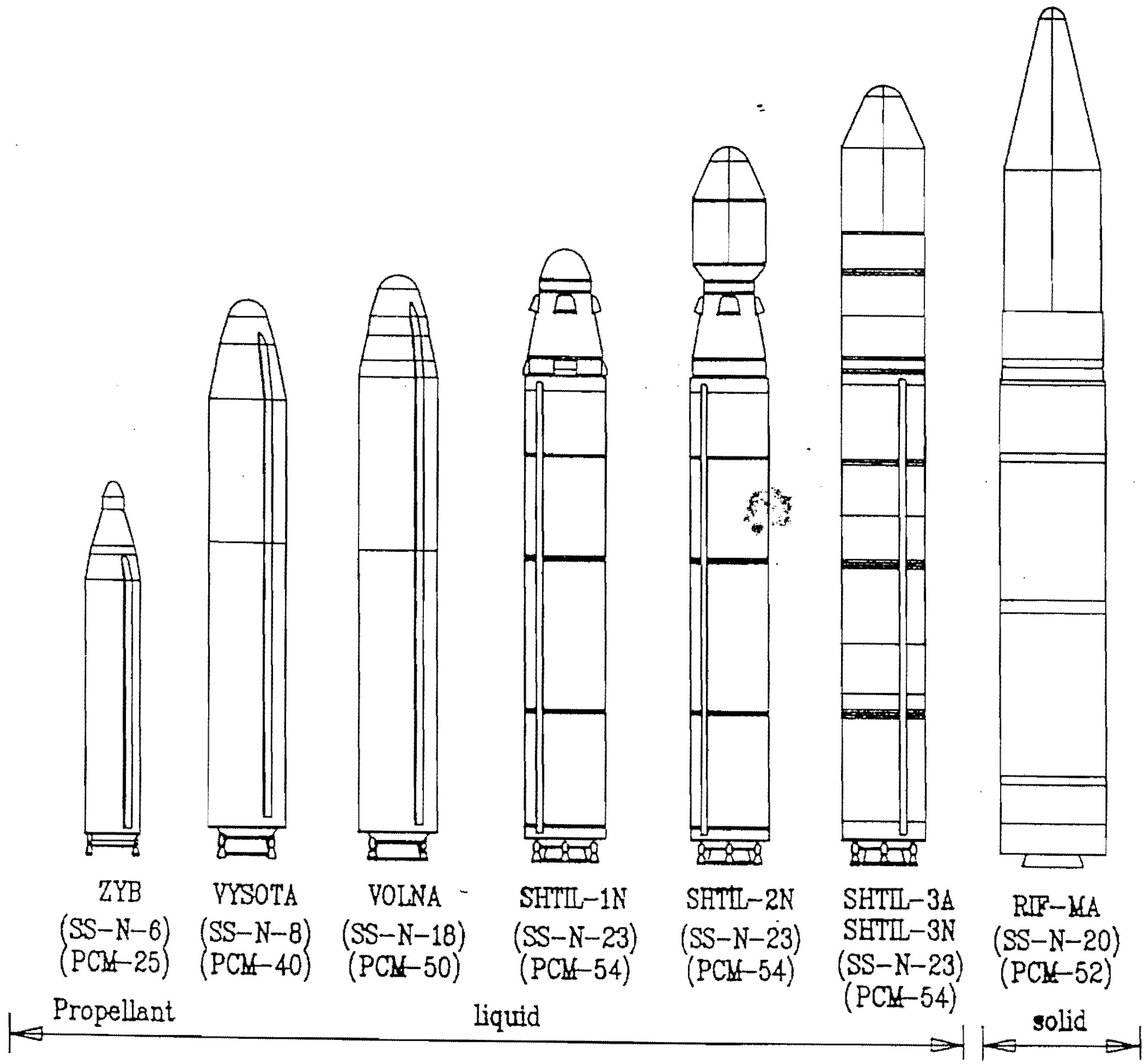
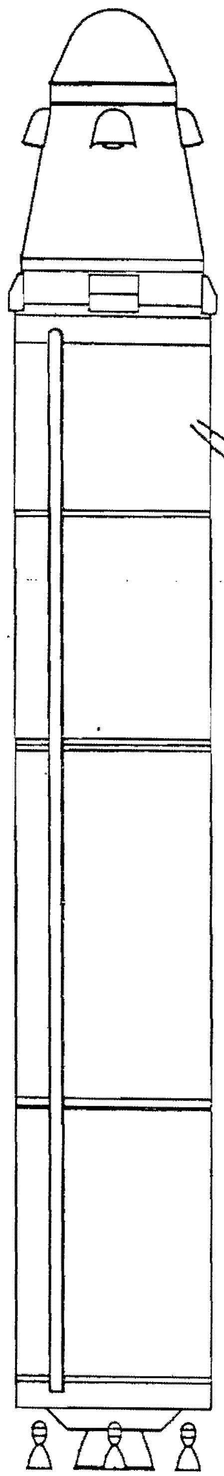
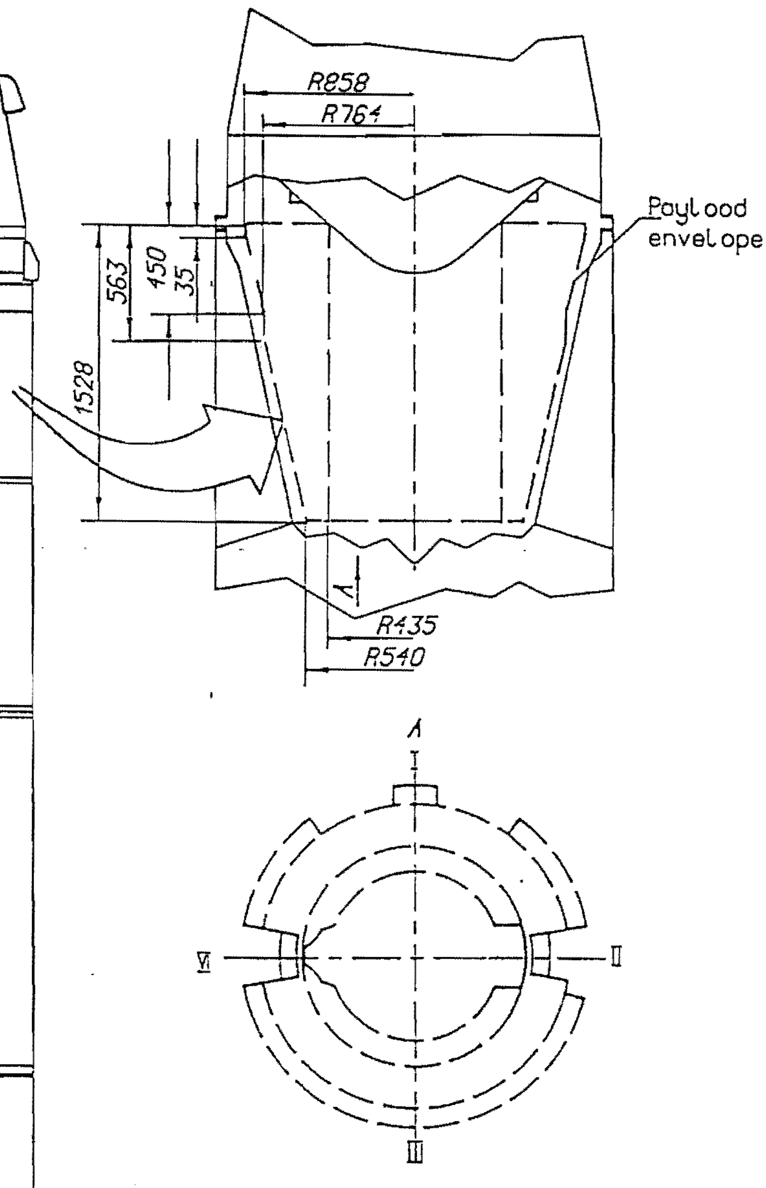


Figure 1
Makeyev Design Bureau (KBM) SLBM Family



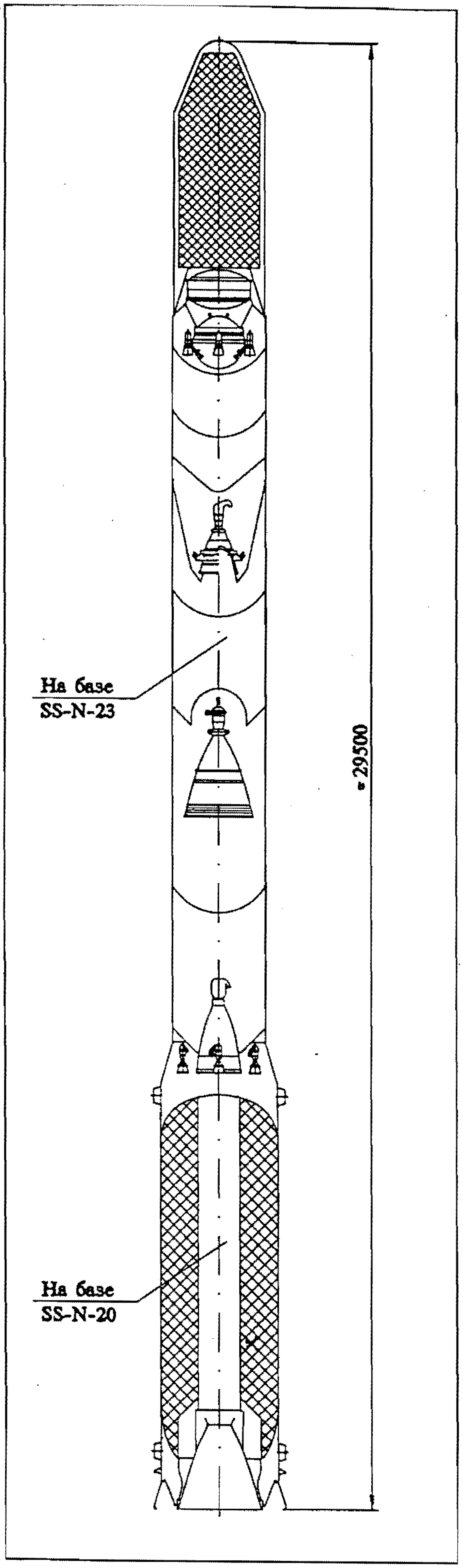


A payload mass placed by the
launch vehicle to circular
orbit inclined 78 deg. versus
orbital altitude is:

200 km - 430 kg
700 km - 185 kg

Figure 2
SHTIL-1N for Demonstration Floating Launch

Figure 3
SURF Space Launch Vehicle

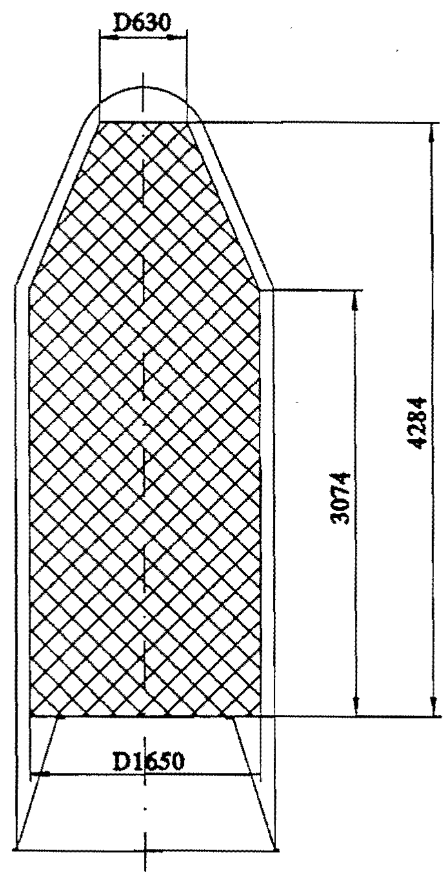


Ракета
Прибой

G ≈ 100000 кг

SURF Rocket
Takeoff Weight, 110 tons

Зона размещения полезной нагрузки (2400кг)



Payload Mass (kg) vs Altitude (km)
· for circular equatorial and polar orbits

Наклонение, град / Высота круговой орбиты, км	0 (экваториальная орбита)	90 (полярная орбита)
200	2400	1840
400	2200	1650
600	2020	1500
800	1850	1360
1000	1700	1230
1200	1570	1110
1400	1460	1000
1600	1360	910
1800	1270	830
2000	1200	770
6400	170	–

Figure 4
SURF Performance to Equatorial & Polar Orbits

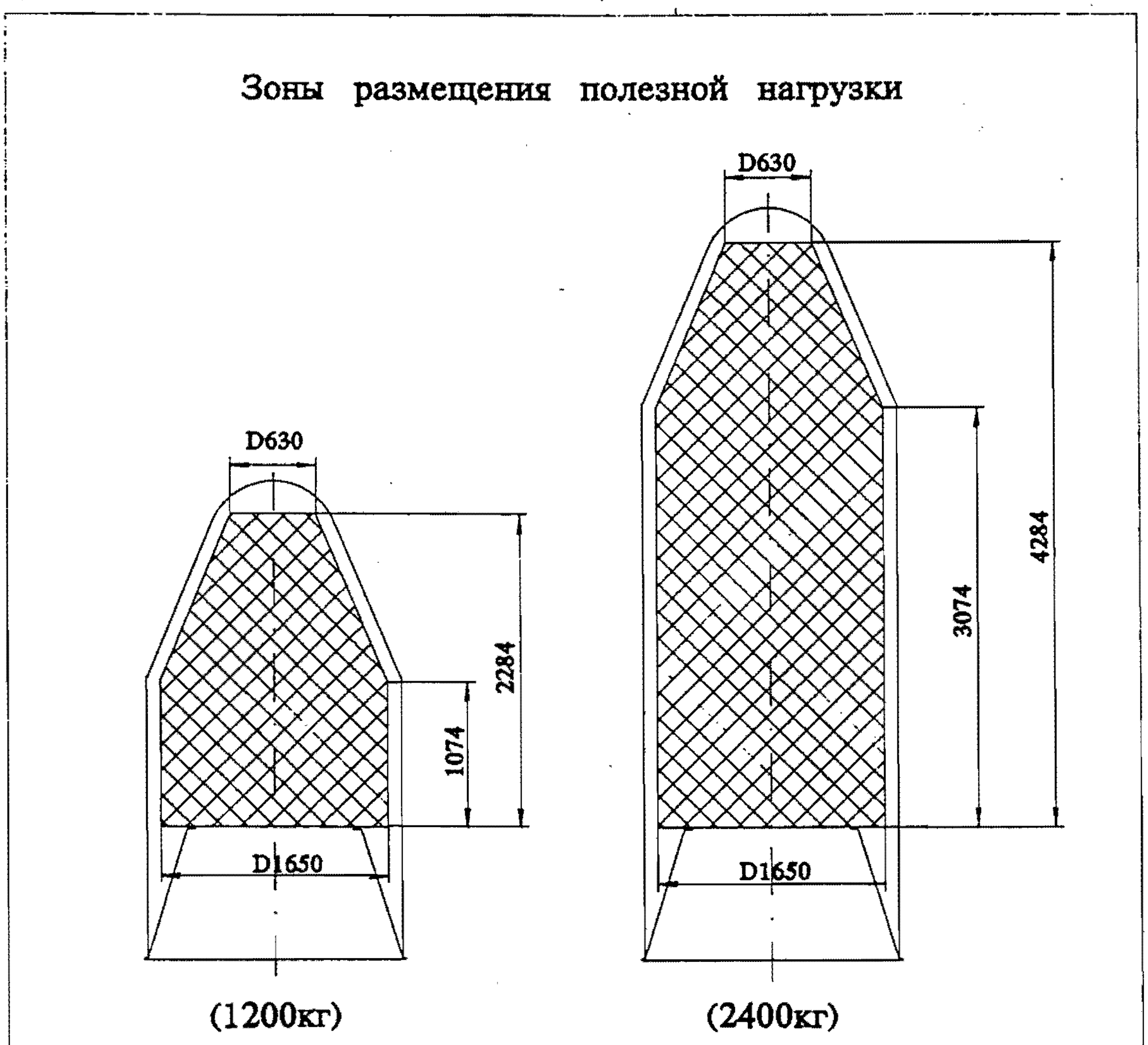


Figure 5
SURF Payload Shroud Options